ATTACHMENT 1A

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Groundwater Depletion Beneath Downtown Tucson, Arizona: A 240-Year Record

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Abstract: Beginning with the foundation date of Spanish Tucson in 1775 and continuing through the 1890s, shallow groundwater and related features, including a perched aquifer, stream-bed springs and a short perennial reach in the Santa Cruz River, progressively disappeared from the Downtown Tucson area. The 20th-Century city grew rapidly, and increasing groundwater withdrawals caused large declines in the regional aquifer of Tucson basin, leaving a second perched aquifer with non-aqueous contaminants beneath Downtown. Isotope data show that this fully perched aquifer retains residual water from the regional aquifer, plus recharge derived from a nearby small watercourse. The present regional aquifer beneath Downtown IS LOCALLY LAYERED AND PARTLY CONFINED, AND CONTAINS WATER 7-20 KA YEARS OLD ORIGINATING AT THE NORTHERN AND southeastern basin margins.

Keywords: *groundwater, urban growth, semi-arid, isotopes, contaminants*

Urban population growth in the semi-arid southwestern region of North America has been rapid since the end of World War II, when population in the USA began to shift to the desirable climates of the "sun belt", and a large population from Mexico moved into border cities in pursuit of economic opportunities afforded at the frontier. Even in cities with access to surface water, the need to supply adequate water for domestic and industrial consumption led to over-exploitation of groundwater. Well-documented examples exist in Albuquerque, New Mexico (Plummer et al. 2004) and the urban area encompassing El Paso, Texas and Ciudad Juárez, Chihuahua (Hibbs et al. 1997), where the static water levels (SWL) fell by tens of meters by the end of the 20th Century. In Tucson, Arizona, where little surface water was available, the population increased from a few thousand in the 1870s to about 1 million by 2012. Figure 1 shows population growth in Pima County, of which Tucson has long been the largest city; in latter years, as the Tucson metropolitan area has extended far beyond the city limits, the county rather than the City of Tucson population has become the better measure of the urban population. The entire metropolitan area depended completely on groundwater until a major engineering project brought Colorado River water to the city by canal in 1992 (Gelt et al. 1999). Small local declines in SWL in Tucson basin in the 1940s (Turner et al. 1943) became large, widespread declines of 15 to more than 50 m by the 1980s (Anderson 1988), and grew locally to as much as 60 m by the 1990s (Gelt et al. 1999).

The effects of over-pumping across the breadth of Tucson basin and the potential for subsidence as a result of dewatering of basin sediments have been reported elsewhere (Anderson 1988; Gelt et al. 1999; Pool and Anderson 2007). Downtown Tucson, the site of the original Spanish settlement towards the west side of the Tucson basin, presents a special case study. The nature of the basin fill (discussed below) differs from that in the broad eastern part of the basin, and there has been little pumping in the area for several decades. Furthermore, historical records offer some insight about changes in hydrologic conditions resulting from two centuries of groundwater exploitation.

In this article, the historical record of groundwater use in Downtown Tucson will be reviewed and interpreted, and a new set of groundwater isotope data will be presented, with the aim of reconstructing the hydrologic evolution of the area since Spanish settlement.

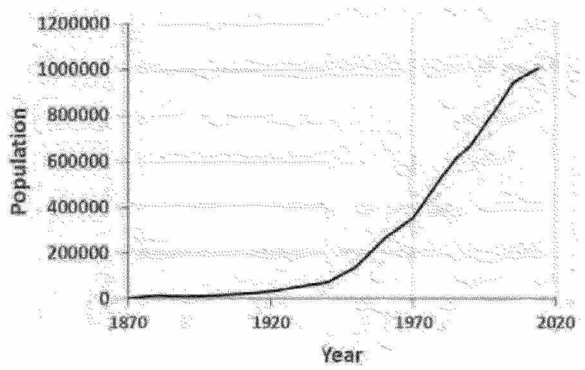

Figure 1. Population of Pima County, 1870-2012. Sources: Pima Association of Governments (2016) and U.S. Bureau of the Census (2016).

Background

Regional Setting

The Tucson basin lies within the watershed of the Santa Cruz River in southern Arizona. The basin is about 30 km (east-west) by 40 km (north-south), and is bounded by mountain ranges of crystalline rock, the Tucson, Santa Catalina, Santa Rita, and Rincon Mountains. Most of the basin floor lies at elevations near 800 meters above sea level (masl). The greater Tucson urban area, which occupies the northern half of the basin, experiences a semi-arid climate with hot summers and cool winters. Rainfall in the central area of the city averages 305 mm annually and is equally distributed between a summer monsoon with brief, localized convectional precipitation, and a fall-winter season of widespread, cyclonic precipitation events associated with Pacific cold fronts or tropical depressions (Gelt et al. 1999).

The basin is of Neogene (post 23 Ma) age, and lies within the Basin-and-Range physiographic province. Regional extension, expressed as detachment faulting followed by high-angle normal faulting, led to rapid deepening of the central part of the basin (Davidson 1973; Eberly and Stanley 1978; Anderson 1987; Dickinson 1999). The basin fill consists of up to 3000 m of alluvial and lacustrine sediments of Oligocene to Holocene age, with fluvial sediments in the flood plains of major streams. Gypsum or anhydrite evaporites occur at depth. Holocene deposits are largely confined to active flood plains. The crystalline basement consists largely of granitic gneiss with Proterozoic and Paleogene protoliths in the Santa Catalina and Rincon Mountains, and of Paleozoic and Mesozoic igneous and sedimentary rocks in the Tucson and Santa Rita Mountains. The principal geomorphic features of the basin include a number of alluvial fans and active flood plains along the major washes, e.g. the Santa Cruz River in the present study area.

Most groundwater in Tucson basin occurs within a single regional aquifer, largely unconfined, hosted in basin-fill alluvium and spanning most of the basin. Static water levels have been strongly modified by decades of pumping, but generally decrease to the northwest, in the direction of the present surface outlet (Gelt et al. 1999). Shallow perched aquifers occur where clayey sediment is common near the surface, and are largely limited to the area immediately east of the Santa Cruz River.

Study Area

This article focuses on the area close to a cross-section of about 5 km, limited to the southwest by Sentinel Peak (a ridge of Oligocene volcanic rock and associated strata jutting east from the Tucson Mountains), and to the northeast by Campbell Avenue (Figures 2 and 3). The area encompasses Downtown Tucson (the commercial center of the city prior to its rapid expansion, and the site of the 18th-Century Spanish settlement), the main campus of the University of Arizona, and part of the flood-plain of the Santa Cruz River. The area straddles the Santa Cruz Fault (Anderson 1987), a high-angle normal fault with the east side downthrown, and one of the principal faults responsible for the deepening of Tucson basin during the Neogene. The basin-fill in this area consists of recent alluvium, about 6 m thick, overlying late Pleistocene Fort Lowell Formation and the Miocene to Pliocene Upper Tinaja Beds. The Fort Lowell Formation truncates the Santa Cruz fault, and is 60 to 90 m thick in the study area. It consists of multiple lenses, varying greatly in thickness and lateral extent, of clay-rich sediment intercalated with silt and sand. The Upper Tinaja Beds consist of gravel, sand, and clayey silt, about

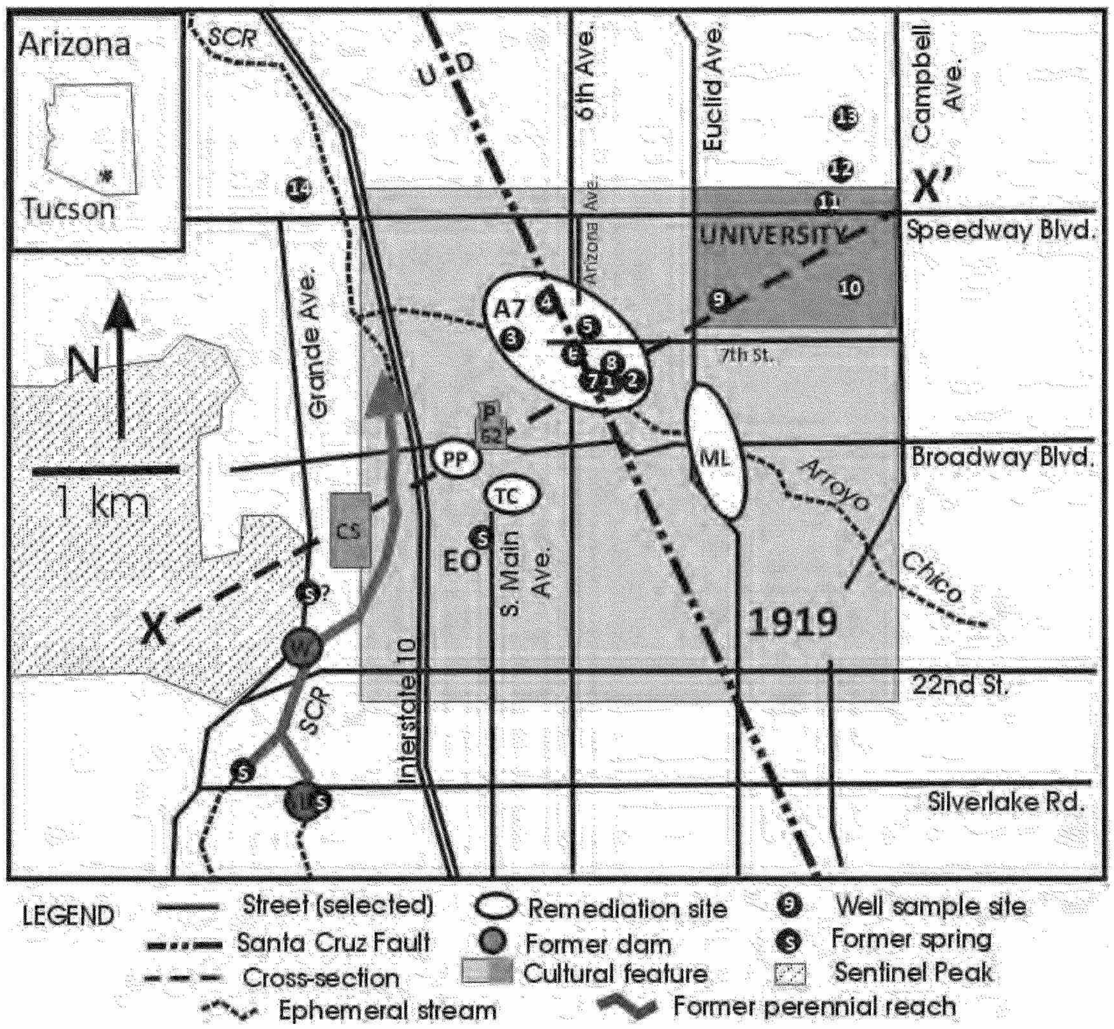

Figure 2. Map of study area. Contaminated sites are Arizona Avenue/7th Street (A7), Mission Linen (ML), Pioneer Paints (PP), and Tucson Convention Center/Police Headquarters (TC). Each contaminated site includes a cluster of wells sampled for the study. Cultural sites are Chuk Shon Village (CS), the Spanish Presidio 1775 (P), and rectangles showing the approximate extent of Tucson in 1862 (62) and 1919. Former dams/reservoirs are Silver Lake (SL) and Warner's (W). SCR = Santa Cruz River. EO = El Ojito Spring. Numbered well sites refer to identifications in Table 1. Information sources: Anderson (1987); Officer (1987); Gelt et al. (1999); Wood et al. (1999); Webb and Leake (2006);. Arizona Department of Water Resources (2016).

30 m thick on the west side of the Santa Cruz fault, and 100 m thick on the east side. (Anderson 1987; City of Tucson Environmental Services 2008). The land surface rises from 710 masl in the entrenched channel of the Santa Cruz River to 750 masl where the cross-section intersects Campbell Avenue. The regional aquifer of the Tucson basin, 3080 m below the surface, is located within the basal Fort Lowell Formation and the Upper Tinaja Beds, and is continuous beneath the study area, with SWLs between 666 and 700 masl. A perched aquifer (or possibly multiple aquifers) 10-30 m below the surface occurs atop clay strata of the Fort Lowell Formation beneath Downtown Tucson, with SWLs at 700 to 711 masl. This fully perched aquifer is locally contaminated with non-aqueous liquid phases (hydrocarbons and chlorinated solvents) discharged in the past from several commercial sites (Figure 2, sites A7, PP, TC, and ML). Both the perched and regional aquifers are at lower

Figure 3. Cross-section of study area (see Fig. 2 for location). Well data are projected on to the section. Well registration numbers (Arizona Department of Water Resources 2016), are given in shortened form as 6 digits (xxxxxx), the full number being 55-xxxxxx.

elevation than the present entrenched bed of the Santa Cruz River. In the study area, water for domestic consumption is pumped only from the regional aquifer at the University of Arizona and from the river floodplain; in other places, samples were available from monitoring wells screened either in the perched aquifer or in the regional aquifer. Figures 3 and 4 show vertical section data derived from drillers' logs available from Arizona Department of Water Resources (2016) using selected logs in which water levels and detailed stratigraphy have been recorded.

Samples for isotope measurement were obtained from five supply wells at the University of Arizona, and from monitoring wells at the following contaminated sites:

1. Pioneer Paint and Varnish, a site contaminated with a variety of organic chemicals (SCS Engineers 2008). Samples were from three wells in the regional aquifer and five in the perched aquifer, all within area PP (Figures 2 and 3).
2. Tucson Convention Center, a site with local gasoline contamination (City of Tucson Environmental Services 2008), with samples from six perched-aquifer wells in area TC (Figures 2 and 3).
3. Arizona Avenue/Seventh Street, a tetrachloroethane (PCE)-contaminated site (Kafura 2007), with samples from two regional-aquifer and six perched-aquifer wells in area A7 (Figures 2 and 3).
4. Mission Linen Superfund site (area ML of Figures 2 and 3, contaminated with chlorinated hydrocarbons), with samples from two perched-aquifer and four regional-aquifer wells.

Previous Groundwater Isotope Research

Previously reported isotope data for groundwater in the study area are available only for wells at the University of Arizona, for the Mission Linen remediation site, and for a few wells in the Santa Cruz flood plain (Kalin 1994; Eastoe et al. 2004; Gu 2005). Eastoe et al. (2004) provided a framework, to be used in this article, for interpreting the origin of Tucson basin groundwater. They presented basin-wide maps of $\delta^{18}O$, $\delta^{34}S$, ^{3}H, and ^{14}C in groundwater, and identified the following: 1.) Localized zones of recent recharge extending several km into the basin from the mountain fronts; 2.) A zone of upward discharge of ancient groundwater, apparently associated with the Santa Cruz fault; and 3.) Distinctive groundwater domains identified by O (water) and S (sulfate) isotope data

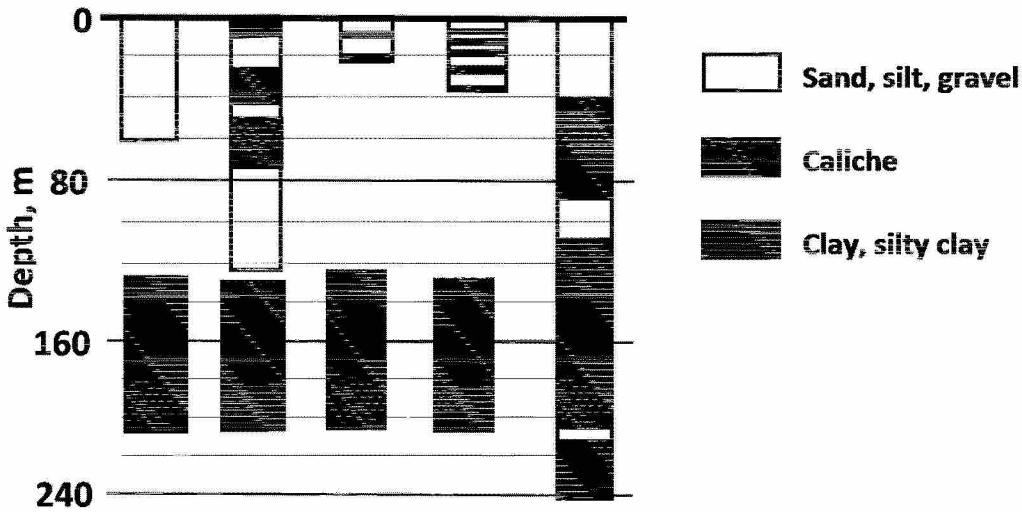

Figure 4. Stratigraphic data from selected drillers' logs (Arizona Department of Water Resources 2016). Well registration numbers are given in shortened form as 6 digits (xxxxxx), the full number being 55-xxxxxx.

in combination, and related to recharge originating from larger streams conveying surface water into the basin. Domain names that will be used here include: A, related to recharge of mountain-derived water from Rillito Creek and its northern tributaries; B, related to the Santa Cruz River; C, related to Cienega Creek; D, related to mountain-derived groundwater possibly discharging upward in the southeastern part of the basin; E, related to Rincon Creek; and F, in the southern part of the basin. The domain map of Tucson basin is shown in Figure 5a, and ranges of $\delta^{18}O$ and $\delta^{34}S$ for domains A to D are shown in Figure 6. Gu (2005) noted that groundwater extraction between the early 1990s (samples of Kalin 1994) and 2000-2005 had led to local replacement of Domain D water by Domain A water (Figure 5b).

Methods

Historical Review

The information presented here is largely drawn from recent historical works in which a review of the primary historical sources is documented.

Sampling and Analyses

Groundwater samples were obtained from active supply wells at the University of Arizona, and during routine sampling campaigns of monitoring wells at several contaminated sites. Isotope measurements were performed at the Environmental Isotope Laboratory, University of Arizona. Stable O and H isotopes of water were measured on a Finnigan Delta S® dual-inlet mass spectrometer equipped with an automated CO_2 equilibrator (for O) and an automated Cr-reduction furnace (for H). Stable S isotopes of sulfate extracted as $BaSO_4$ were measured on a Thermo Electron Delta Plus XL® continuous flow mass spectrometer equipped with a Costech® elemental analyzer for preparation of SO_2. Tritium was measured on 0.18 L water samples after electrolytic enrichment. Carbon-14 was measured on CO_2 extracted from 50 L water samples by acid hydrolysis of dissolved inorganic carbon; the carbon was converted to benzene. Both tritium and carbon-14 were measured in a Quantulus 1220® Spectrometer by liquid scintillation counting. Routine analytical precisions (1σ) are 0.08‰ (O), 0.9‰ (H), 0.15‰ (C), and 0.15‰ (S). Routine detection limits are 0.6 TU for ^{3}H and 0.2 percent modern carbon (pMC), ^{14}C, undiluted sample.

Correction of ^{14}C Data

The procedure follows Clark and Fritz (1997, 210 ff), using the method based on mixing of stable carbon isotopes, assuming a C_3:C_4 ratio of 3:1 in decaying plant matter in soil, slightly alkaline conditions of initial infiltration of

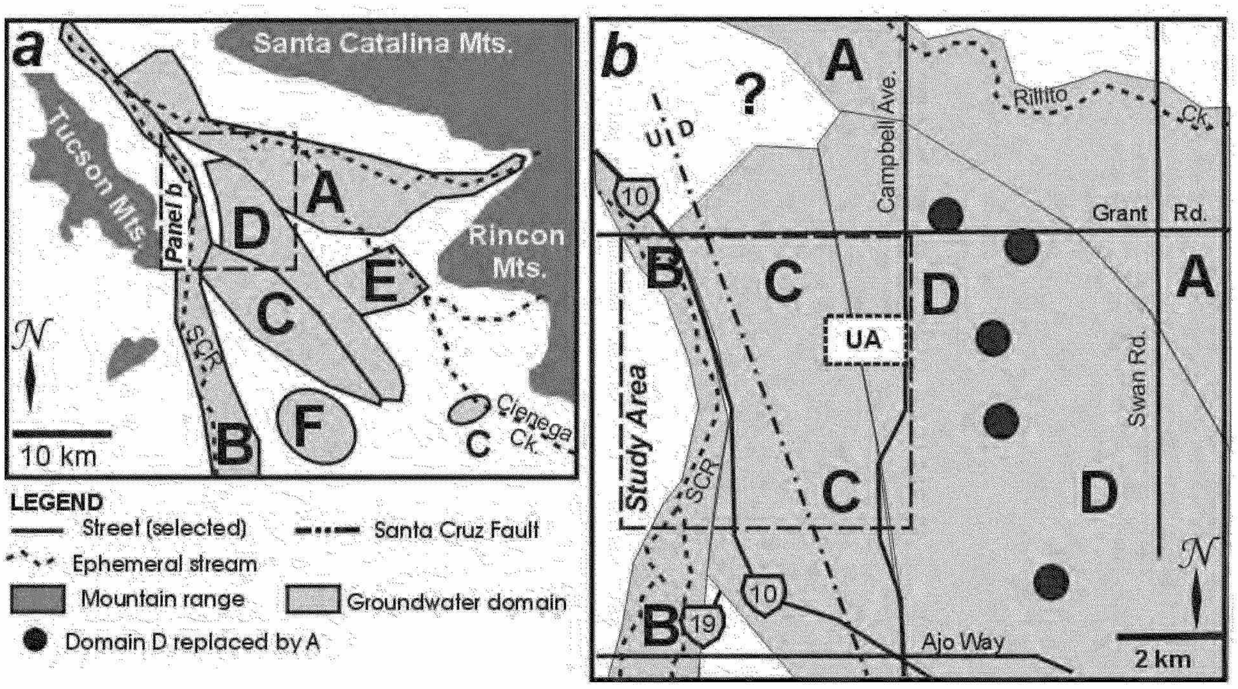

Figure 5. (a) Water domain map of Tucson Basin, after Eastoe et al. (2004); **(b)** Updated water domain map of the area encompassing the study area. UA = University of Arizona; SCR = Santa Cruz River; shaded areas labeled A, B, etc. are domains A, B, etc.

rainwater, and $\delta^{13}C$ values of -1 or -2‰ for rock carbonate (unpublished data of the Laboratory of Environmental Geochemistry). This set of assumptions has been found to yield plausible results for Tucson Basin, with dilution ratios between 0 and 1, and corrected ^{14}C activities less than about 150 pMC.

Review – History of Groundwater Use in Tucson

Father Eusebio Kino, an early emissary of the Spanish Empire, travelled to the area now occupied by Tucson in the 1690s. There he encountered two villages, Wa:k and Chuk Shon, of the Tohono O'odham people (known previously to Europeans as the Papago), several hundred households in total (Sonnichsen 1982; Officer1987). Each village depended on surface water from short (a few kilometers) perennial reaches of the Santa Cruz River. Water was conveyed from the river to fields around the villages through a system of controlled ditches (Kupel 1986). There is no indication of more extensive perennial reaches in the historical record (Wood et al. 1999; Logan 2002). The water discharged in stream-bed springs from upstream groundwater basins across sills of impermeable rock (Wood et al. 1999). Another spring is reported near Chuk Shon, at the foot of Sentinel Peak (Sonnichsen 1982), but other authors do not mention it; Sonnichsen may have been referring to one of the stream-bed springs. The Chuk Shon perennial reach terminated near the village, or at times a few kilometers downstream (Bourke 1891; Sonnichsen 1982). Native Americans already had a long history of water engineering in the area. About 3000 years ago, canals channeled ephemeral stream water to a settlement known to archaeologists as Las Capas, 15 km downstream of the present city center (Palacios-Fest et al. 2001). Systems of controlled irrigation ditches and shallow dug wells in the flood plain have been excavated in a site dating from 1000 years ago (Logan 2002).

What had been a sufficient water supply for the Tohono O'odham residents became inadequate in the decades following the founding of the Spanish Presidio (fort) on a low mesa opposite Chuk Shon (Figure 2) in 1775. The Presidio was to become the nucleus of Tucson. Any appropriation of local surface water for the domestic and agricultural

Figure 6. Stable S isotope (sulfate) and O isotope (water) data for the perched and regional aquifers in the study area. Fields A, B, C, and D correspond (with slight modification of field C) to basin-wide groundwater domains as defined in Eastoe et al. (2004).

needs of the few hundred residents of the Presidio inevitably left the Chuk Shon village with insufficientwater (Sonnichsen 1982). The site of the presidio was close to El Ojito ("the little spring"), variously described as a spring, a well, and an artesian well (Officer 1987; Logan 2002), from which domestic water was drawn until the 1880s. This may originally have been a spring into which a well was excavated as the supply declined. The water supply was augmented from dug wells within the Presidio and the adjacent Mexican village. Water was encountered within 4 to 5 m of the surface, and it is said to have deteriorated in quality after a brief period of exploitation (Kupel 1986). Local tradition (e.g., Arizona Historical Society 2016) attributes the final drying of El Ojito and the shallow aquifer beneath the village to the 1887 earthquake with epicenter near Bavispe, Sonora. While acute hydrological phenomena correlating with the earthquake are plausibly documented elsewhere in southeastern Arizona, Dubois and Smith (1980) cited no textual reference earlier than Bennet (1977) as evidence of possible hydrological effects in Tucson.

Modest population growth in the latter half of the 19th Century and competition for water between the townspeople and farmers led to the initiation of engineering projects to enhance water supply from surface water and groundwater. Low dams were built on the Santa Cruz River in 1859 (Silver Lake) and 1870 (Warner's) to impound flow from the stream-bed springs supplying the Chuk Shon perennial reach (Figure 2); these provided power to flour mills, and controlled water for irrigated fields, mainly on the flood plain west of Tucson (Kupel 1986; Officer 1987, 289). The river bed adjacent to Tucson was excavated by Sam Hughes in 1887 in an attempt to recover shallow riparian groundwater (Logan 2002). Finally, as steam-driven pumps and drills became available, the community developed well-fields in order to exploit deeper groundwater. The first was about 1 km south of the town-site, and, in 1893, another was installed in the Santa Cruz flood plain 10 km south of the town (Kupel 1986; Logan 2002).

The excavation in the river bed by Sam Hughes was followed by a series of large floods in the late 1880s, and the excavation became the point of initiation of an entrenched river reach that grew to 29 km by 1920. Local tradition (e.g., Logan 2002) holds that the excavation was the principal cause of the entrenchment, which persists to the present. However, similar entrenchments began concurrently elsewhere in the southwestern USA (Bryan 1925) and a number of human-associated and climatic factors may have favored the regional entrenchment of watercourses (Betancourt 1990). The 1-5 m entrenchment along the Santa Cruz River permanently lowered the water table of the flood plain, destroyed the dams, and forced the construction of more complicated diversion canals for irrigation (Logan 2002).

Kupel (1986) outlined the subsequent history of groundwater use in Tucson, summarized briefly here. Artesian water was located at the foot of Sentinel Peak in 1896, but no further such discoveries followed near the town. Evolving pump technology put deeper groundwater resources within reach of the community, and provided it with a water supply through most of the 20th Century. By the 1960s, SWLs in the study area had fallen 15-30 m relative to pre-development levels (Anderson 1987). In the second half of the century, population growth became so rapid, and the demand for potable water so large, that the finite nature of the groundwater supply and the need for water conservation were recognized in civic deliberations. The advent of the Central Arizona Project, channeling Colorado River water to Tucson, enabled the city to provide an alternative water source, and to cease pumping from its central well field by the 1990s. The urban population, however, continues to increase (Figure 1).

Two Tucson place names might suggest a historical association with groundwater. Dunbar/Spring Neighborhood, immediately north of Downtown Tucson, is in fact named for pioneer residents Paul Dunbar and John Spring, and was not the site of a spring (Dunbar/Spring Neighborhood Association 2016). Flowing Wells Irrigation District, 7-8 km north of downtown, began as the Flowing Wells Water Company exploiting the artesian groundwater near Sentinel Peak, and later moved its operations to its present territory where no artesian wells are recorded (Kupel 1986).

Isotope Data

Data are listed in Table 1. Figure 6 shows new S and O isotope data for the perched and regional aquifers in the study area in relation to domain classification of Eastoe et al. (2004). Figure 7 shows O and H isotope data for the two aquifers. The interpretation of δD *vs.* $\delta^{18}O$ plots such as Figure 7 is based on the following general observations (more details can be found in Clark and Fritz 1997, and references therein). At most locations worldwide, annual averages of O and H isotopes in precipitation plot on a line of slope near 8, the Global Meteoric Water Line (GMWL). Partially evaporated meteoric waters plot to the right of the GMWL. Progressive evaporation of a particular sample of water yields residual water having isotope compositions plotting on a line with slope commonly between 3 and 5, depending on relative humidity.

Considering Figures 6 and 7 in conjunction, the following observations emerge:

Perched aquifer

Most samples plot within or very close to the domain C box in Figure 6, indicating the dominance

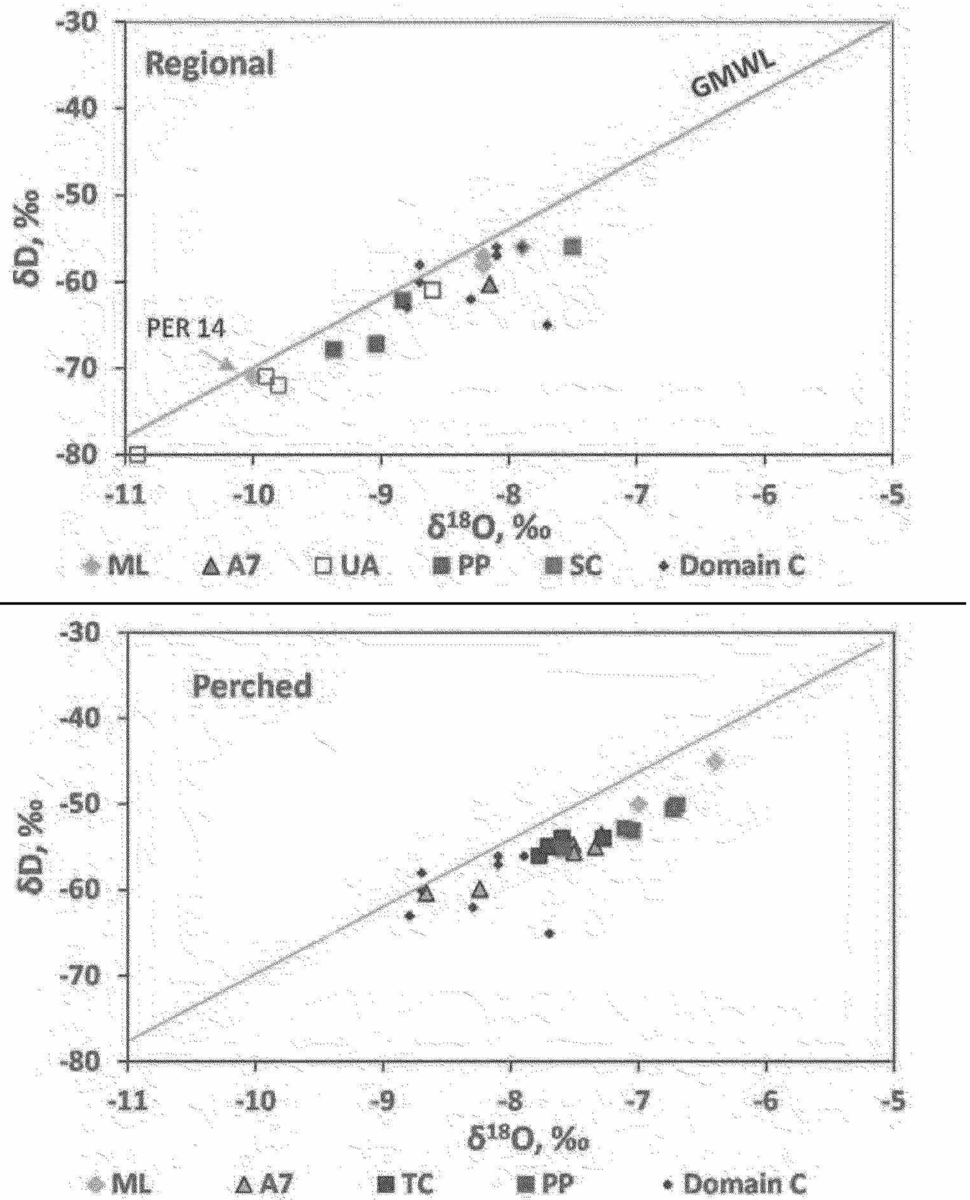

Figure 7. Stable O and H isotope data for the perched and regional aquifers. Data for domain C water from Eastoe et al. (2004).

of sulfate from domain C water. Outliers, from sites ML and PP, to the right of box C can be explained by reference to Figure 7, where the δD and $\delta^{18}O$ data plot on one or more evaporation trends of slope near 4.5; the outliers correspond to the more evaporated samples. The trend emerges from the fieldof domain C samples in parts of Tucson basin upgradient from the study area (data from Eastoe et al. 2004). Site PP has a very broad range of $\delta^{34}S$, 0 to +18‰. No water from domains A, B, and D was detected. The two samples from the ML site contained elevated tritium (15 and 40 TU) when sampled in 2003.

Regional Aquifer

The O and H isotope data (Figure 7) have domain C water as one end member, but in contrast to the perched aquifer, extend to more negative values typical of domains A and D. Domain C water is found at the UA, ML, and A7 sites. Domain D

Table 1. Well Data and Analyses.

Area Well (screen, mbgs)	ADWR Reg. No. 55-	Aquifer	Collar altitude masl	Depth mbgs	SWL masl	$\delta^{18}O$ water ‰	δD water ‰	$\delta^{34}S$ sulfate ‰	Tritium TU	^{14}C pMC	$\delta^{13}C$ DIC ‰	Corr. age KA
ML (sampled 2003)												
UAM 1 (63-81)		RC	724.7	82.1	658.3	-8.2	-58	14.1	1.0			
UAM 2 (61-79)		RC	724.7	80.6	660.2	-8.2	-57	13.9	1.9			
PER 14 (143-159)		R	732.7	158.5	681.5	-10.0	-71	7.8	<0.6	15.7	-7.2	12
MLR-1 (79-105)		R	731.6	106.1	677.7	-7.9	-56	12.0	<0.7	20.1	-8.6	8
PEP-11		P	733.7	30.3	704.9	-6.4	-45	10.3	14.8			
PEP-19		P	731.7	30.3	702.9	-7.0	-50	11.1	39.6			
PP (sampled 2008)												
WR250A	535809	P	717	13.6	706.1	-7.1	-53	17.9				
WR251A	541080	P	717	13.6	706.1	-7.0	-53	1.4				
WR252A	542382	P	717	13.6	706.1	-7.6	-55	11.7				
WR269A	556250	P	717	15.2	706.4	-6.7	-50	8.9				
PPM529A	907396	P	717	17.3	701.8	-6.7	-51	-0.2				
WR248A	529533	R	717	42.4	683.7	-8.8	-62	8.1				
WR249A	529534	R	717	53.0	683.7	-9.4	-68	7.8				
WR271A	556258	R	717	42.4	682.2	-9.0	-67	6.6				
TC (sampled 2008)												
CEP-518A	906115	P	726	23.0		-7.7	-55	10.5				
CEP-519A	906116	P	726	21.8	707.5	-7.6	-54	10.8				
CEP-520A	906117	P	726	21.8	707.5	-7.6	-54	12.3				
HQUST531A	907928	P	726	22.4	706.9	-7.8	-56	12.6				
HQUST532A	907927	P	726	22.1	706.9	-7.7	-55	12.3				
HQUST533A	907929	P	726	21.8	707.5	-7.3	-54	11.3				

Table 1 Continued.

Area Well (screen, mbgs)	ADWR Reg. No. 55-	Aquifer	Collar altitude masl	Depth mbgs	SWL masl	$\delta^{18}O$ water ‰	δD water ‰	$\delta^{34}S$ sulfate ‰	Tritium TU	^{14}C pMC	$\delta^{13}C$ DIC ‰	Corr. age KA
<u>A7 (sampled 2007)</u>												
1 MW-PD-6		P	722.1		700.8	-7.7	-55					
2 MW-PD-7		P	721.9		700.9	-7.3	-54					
3 MW-PD-31		P	715.9		698.6	-8.7	-60	15.7				
4 7AZP-6		P	722.5		697.9	-7.5	-55	14.5				
5 7AZP-7		P	722.8		699.6	-7.3	-55	11.4				
6 YC-6		P	718.9		699.1	-7.5	-56					
7 MW-PD-19 R		R	720.0		667.6	-8.2	-60	11.0				
8 7AZR-1 R		R	720.0		667.1	-8.2	-60	10.9				
<u>UA (sampled 2006-2010)</u>												
9 Park Av. (206-297)	217003	R	737	306.1		-10.9	-80	9.8		4.4	-8	19-20
10 Optical Sciences	201737	R	745	206.0	666.2	-9.8	-72	12.4	<0.5	9.7	-7.2	7-8
11 North cooling	528535	R	747	212.1	674.3	-9.9	-71		<0.9			
12 UMC South	618689	R	748	121.2	681.9	-8.6	-61	10.9	0.7			
13 UMC North	618688	R	743	139.4	697.8	-8.6	-61	11.6	<0.4	14.8	-8.6	11-12
<u>SC (sampled 1999)</u>												
14 Arizona School for Deaf and Blind	600785	R	712	127.3	681.7	-7.5	-57	6.6	11.1			

Explanation: No entries where data are unavailable

ADWR Reg. No. = Arizona Department of Water Resources registration number; mbgs = meters below ground surface; SWL = static water level

masl = meters above sea level; RC = regional, confined; TU = tritium units

R = regional; P = perched

water is found at the UA site, and domain A water at the ML and PP sites (Figure 6). Domain B water was encountered only in the flood plain of the Santa Cruz River. Available tritium measurements (tritium units, TU) are either low (0.7 to 1.9 TU) relative to the 5.2 TU average for Tucson rain (Eastoe et al. 2011) or below detection. Available ^{14}C measurements show low ^{14}C content, 4 to 15 percent modern carbon (pMC). Wells 10 and 13 at the UA site have corrected bulk residence times of 7-8 and 11-12 Ka. The Park Avenue well (9) at the UA site is 300 m deep, much deeper than other wells in the study area, and has unusually low $\delta^{18}O$ values (-10.9‰) for this part of the basin where most water has $\delta^{18}O$ values between -9 and -10‰ (Eastoe et al. 2004). The Park Avenue well (9) also has the lowest pMC measurement, 4.4, of the entire data set for Tucson basin, corresponding to bulk residence ages of 19 to 20 Ka.

Vertical Structure of Regional Aquifer

The ML site, with wells screened at four different depth ranges (Table 1), provides a view of the complexity of the regional aquifer in the area (Figure 8). The upper part of the aquifer, corresponding to screens 61-81 m below the surface, is essentially unconfined (the SWLs lying below those of the perched aquifer), and the samples contained tritium at 1.0 and 1.9 TU. Two deeper wells (MLR-1 and PER 14) intersect a confined, pressurized aquifer with SWLs higher than those of the overlying aquifer, and containing water with bulk residence ages of 8 Ka (screen 79-105 m below the surface) and 12 Ka (PER 14, screen 143-159 m below the surface). The unconfined aquifer and the upper part of the confined aquifer contain domain C water, while sample PER 14 is domain A water. The Park Avenue (9) well 1 km to the north, screened at 206-297 m below the surface, yields water close to domain D composition (Figure 6).

Discussion

Perched Aquifers

Drillers' logs indicate a complex interlayering of clay-rich and coarser clastic units within the Fort Lowell Formation beneath Downtown Tucson. While the continuity of individual clay units is not evident from the logs (Figure 4), the presence of a perched aquifer at 700 to 711 masl beneath most of the study area suggests that at least one such unit is continuous across the study area. This impermeable layer has prevented a variety of contaminants from infiltrating to greater depths below the study area.

Historical descriptions of shallow water beneath the Spanish Presidio in the late 18th Century imply the existence of a higher perched aquifer (Presidio aquifer, Figure 3) at that time, presumably atop one

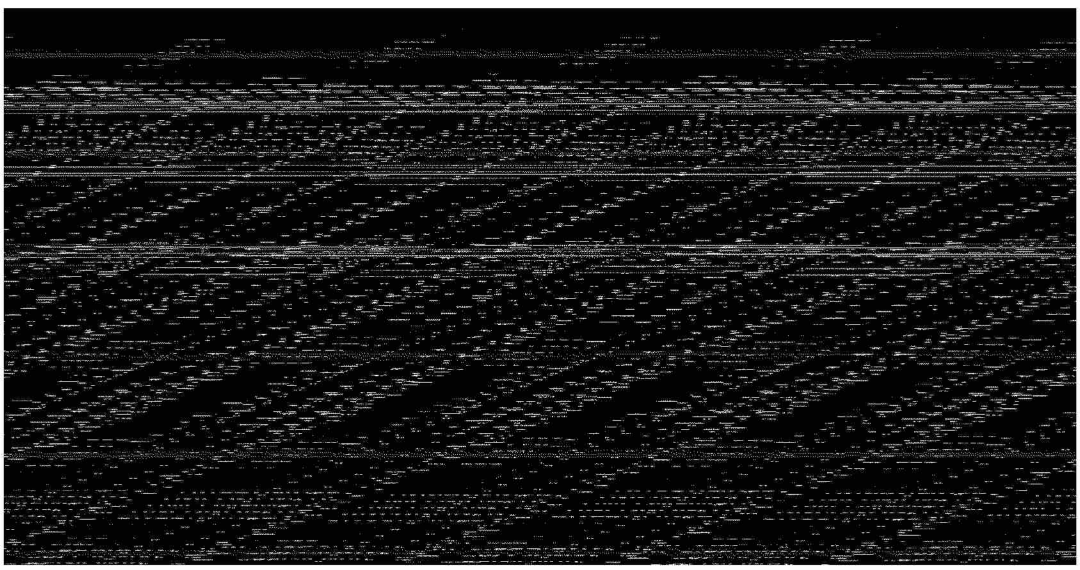

Figure 8. Schematic section of the perched and regional aquifers at the ML site and the Park Avenue (9) well. Bold vertical lines indicate wells. A, C, and D refer to water domain types, as described in the text.

of the shallow clay aquitards in the area (Figure 4). The aquifer was most likely recharged from Arroyo Chico to the east and north of the Presidio or from smaller washes that pass through the study area, and discharged at El Ojito spring. The Presidio aquifer dried up by the late 19th Century, an event that may have coincided roughly with the 1887 earthquake, but may equally have been the first negative consequence of human activities (over-exploitation, or deepening of wells through the aquitard beneath the aquifer).

The present-day perched aquifer receives recharge from Arroyo Chico at the ML site. The high tritium content at that site is either from bomb-spike tritium, 1960-1970, or from tritium released from the nearby American Atomics factory between 1970 and 1980 (Eastoe et al. 2011). The recharge is evaporated, and mixing of such water with domain C water generates the isotope trend in Figure 7. Domain C water originates from Cienega Creek in the southeastern part of the basin (Figure 5a) and is labeled by Permian marine sulfate that is not present in the study area (Eastoe et al. 2004). The presence of domain C water in the perched aquifer shows that the pre-development regional water table was above the present perched aquifer, and that what is now a perched aquifer was a part of the regional aquifer.

The broad range of $\delta^{34}S$ (-0.2 to +17.9‰) at site PP is unusual in Tucson basin, where most groundwater has values between +4 and +15‰ (Eastoe et al. 2004). The higher values may reflect partial sulfate reduction by microbes exploiting organic liquids as a carbon substrate. The lower values remain unexplained, but may be related to chemical contamination at the site, for example by sulfuric acid, which is commonly used as a paint remover and generally has a $\delta^{34}S$ value around 0 ‰.

Regional Aquifer

Prior to development, the regional aquifer beneath Downtown Tucson contained mainly domain C water, as indicated by residual water in the perched aquifer. In its present form, it is a set of unconfined and confined units containing, from upper to lower layers, water of domains C, A, and D. The decline in level of the regional aquifer has been due to basin-wide pumping, and presumably led to the isolation of the perched aquifer prior to the 15-30 m fall in water levels mapped beneath Downtown Tucson by Anderson (1988).

An updated version of the basin-wide water domain map for the regional aquifer (Figure 5b) shows that domain A water appears beneath the Downtown study area at sites PP and ML, remote from its main occurrence near Rillito Creek and its tributaries, but localized near the Santa Cruz fault. At site ML, the domain A water is ancient (Table 1). Upward discharge of ancient domain A water close to the fault also occurs elsewhere in Tucson basin (Eastoe et al. 2004), and appears to be a basin-scale phenomenon. Domain A water has also replaced domain D water outside the Downtown study area at several sites sampled in the early 1990s (Kalin 1994) and repeated in the early 2000s (Gu 2005). These changes have coincided with, and are most likely due to, basin-wide decline in the level of the regional aquifer (Gelt et al. 1999).

Role Of The Santa Cruz River

The original SWL of the regional aquifer was probably limited by the altitude of the pre-entrenchment channel of the Santa Cruz River, into which the aquifer most likely discharged. Eastoe et al. (2004) noted very limited eastward infiltration of domain B water from the Santa Cruz flood plain, but left open the possibility that the Downtown area, at that time unstudied, might form part of domain B. The present study shows that no infiltration from the flood plain has reached either the perched or the regional aquifer at the Downtown sampling sites. Prior to development, river water could not displace domain C water present at higher elevations. The present-day regional aquifer appears to have lower SWLs in the flood plain, where it is heavily pumped upgradient of the study area, than immediately to the east beneath Downtown, where it is not pumped (Figure 3). Infiltrating river water appears to remain in the relatively unconsolidated sediment of the flood plain, rather than moving laterally into the perched and regional aquifers.

Management Implications

The decline of the regional aquifer to levels below those of the present perched aquifer beneath Downtown Tucson has fortuitously isolated a variety of dangerous contaminants above an aquitard, as noted above. This observation, while not part of the findings of this study, has clear implications for aquifer management in the Downtown area. Wells continue to be drilled in the area for water quality monitoring, or for supply of non-potable water (e.g., well 700375, Arizona Department of Water Resources 2016). New wells must be properly constructed, and old wells carefully decommissioned, so as to prevent downward leakage from the perched aquifer. Groundwater in the contaminated perched aquifer moves slowly (City of Tucson Environmental Services 2008). This study has identified a recharge zone of the perched aquifer along Arroyo Chico at the ML site, and shown that recharge since the separation of the perched and regional aquifers has been insufficient to date to flush old regional aquifer water from the perched aquifer. Such information may be of use in future management of the perched aquifer contaminants.

Conclusions

Since European settlement began in Tucson 240 years ago, groundwater conditions have deteriorated steadily. The small perched aquifer that supported the first settlement dried by the late 1800s. Water levels in the regional aquifer have fallen, in the first instance as a result of stream-bed entrenchment and then as a result of riparian groundwater pumping, leading to the loss of stream-bed springs. Evolution of pumping technology and rapid growth of population during the 20th Century led to accelerating declines in the regional aquifer, and the isolation of a second perched aquifer in the Downtown area.

New isotope data show that domain C groundwater of Eastoe et al. (2004) dominated the regional aquifer in the study area before the rapid decline in water level. Domain C water is ultimately derived from Cienega Creek to the southeast and is estimated to have taken 8 to 12 Ka to flow across Tucson basin to Downtown. Since its isolation from the regional aquifer, the perched aquifer has received a little recharge from Arroyo Chico, but insufficient to flush out residual domain C water. Samples from the lowered regional aquifer include mountain-derived groundwater (domains A and D), with the domain A water supplied by upward discharge along the Santa Cruz fault. No recharge from the Santa Cruz River has been detected.

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Chris Eastoe graduated with a Ph.D. in Economic Geology from the University of Tasmania in 1979. He was appointed Assistant Professor at the University of Arizona in 1982. From 1990 to his retirement in 2015, he coordinated/co-directed the Environmental Isotope and Radiocarbon Laboratories at the University of Arizona, and undertook research in the application of isotope techniques to a variety of earth science problems. He may be contacted at Department of Geosciences, 1040 E 4th St., Room 208, Tucson, AZ 85721; or by email at eastoe@email.arizona.edu.

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ATTACHMENT 1B

U.S. Copper Porphyry Mines

Report

THE TRACK RECORD OF WATER QUALITY IMPACTS RESULTING FROM PIPELINE SPILLS, TAILINGS FAILURES AND WATER COLLECTION AND TREATMENT FAILURES.

JULY 2012

(REVISED 11/2012)

EARTHWORKS

U.S. COPPER PORPHYRY MINES:

The track record of water quality impacts resulting from pipeline spills, tailings failures and water collection and treatment failures.

EARTHWORKS, July 2012
(Revised 11/2012)

By Bonnie Gestring

Reviewed by Dave Chambers Ph. D.,
Center for Science in Public Participation (CSP2)

Photos, top to bottom:

Yankee Doodle tailings pond by Eco light
Chino Mine by Gila Resource Information Project (GRIP)
Sierrita Mine by Eco light
Bird fatality at Tyrone Mine by Jim Kuipers

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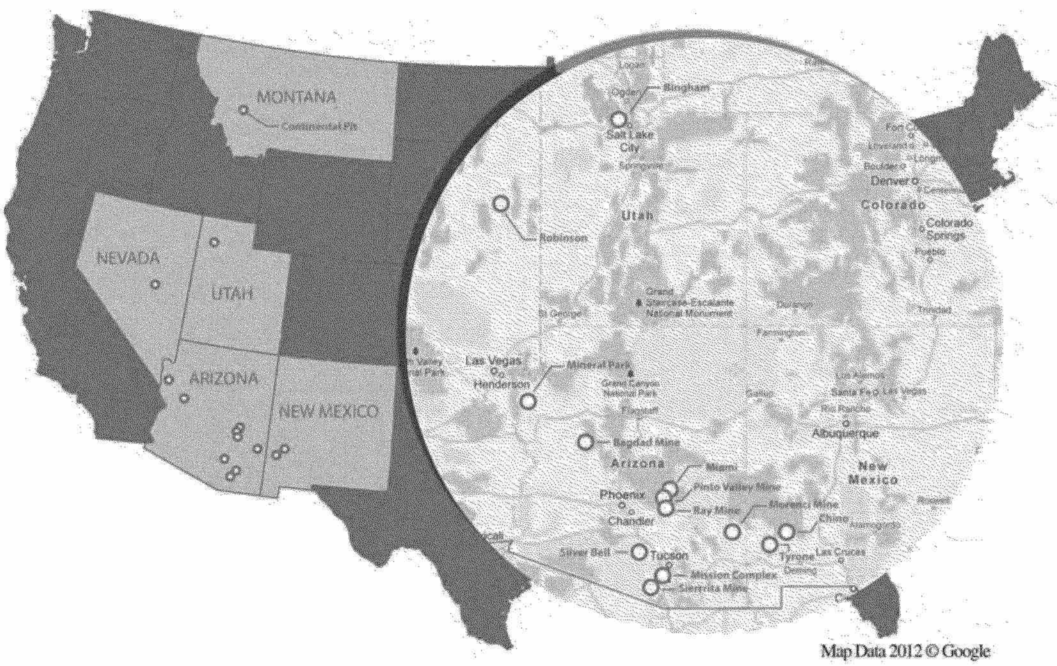

INTRODUCTION:

The Pebble Mine is proposed for development at the headwaters of the Bristol Bay watershed in southwest Alaska, which supports the world's largest wild sockeye salmon fishery. According to current ore estimates, the Pebble Mine would be the largest copper porphyry mine in the U.S., if constructed.

Currently, the U.S. Environmental Protection Agency (EPA) is completing a watershed assessment to evaluate the potential impacts of large-scale mining on water quality and fishery resources using a mine scenario that reflects the expected characteristics of mining operations at the Pebble deposit.

The purpose of this report is to compile the record of pipeline, seepage control and tailings impoundment failures at operating copper porphyry mines in the U.S., and to document associated water quality impacts.

Copper porphyry is a form of copper deposit that is often characterized as low-grade, typically with 0.4% and 1.0% concentration of copper, and containing other minerals such as gold, molybdenum, and other trace elements in the ore body. Copper porphyry deposits are almost always mined in industrial-scale open pit operations.

Contact water drainage from porphyry deposits commonly has concentrations of aluminum, cadmium, copper, iron, manganese, lead, and zinc that exceed US drinking-water limits, which were developed to protect public health, and also commonly exceeded for cadmium, copper, lead and zinc aquatic life standards, developed to protect fish and other sensitive aquatic organisms.[1]

METHODS:

We reviewed state and federal documents and a federal database for fourteen copper porphyry mines currently operating in the U.S. with respect to three failure modes: pipeline spills or other accidental releases, tailings spills or tailings impoundment failures, and failure to capture and treat mine seepage.

The 14 mines represent 87% (14 out of 16) of currently operating copper porphyry mines, and 89% of U.S. copper production in 2010– the most recent data on copper production available from the U.S. Geological Survey. The mines were chosen based on an operating record of more than five years. These mines provide a representative view of the types of environmental impacts resulting from the development of copper porphyry deposits, focusing on pipeline spills, tailings failures, and water collection and treatment failures.

RESULTS:

Our research shows that copper porphyry mines are often associated with water pollution associated with acid mine drainage, metals leaching and/or accidental releases of toxic materials. We found that all of the mines experienced at least one failure, with most mines experiencing multiple failures:

- At 14 of the 14 mines (100%), pipeline spills or other accidental releases occurred. The most frequent spills were reported at the Ray Mine in Arizona, where over fifty pipeline spills occurred from 1988 to 2012. Examples of recent pipeline spills include a 2012 spill at the Ray Mine which washed tailings into the Gila River, and a 2008 pipeline spill at the Morenci Mine of 186,000 gallons of sulfuric acid along two miles of Chase Creek - a tributary of the San Francisco River.

- At 13 of the 14 mines (92%), water collection and treatment systems have failed to control contaminated mine seepage, resulting in significant water quality impacts. The development of acid mine drainage was associated with the most severe and lasting impacts. For example, at the Tyrone and Chino mines – the two largest copper porphyry mines in New Mexico, seepage from tailings impoundments and waste rock piles have resulted in surface and/or groundwater pollution. The State of New Mexico and U.S. Department of Justice have filed natural resource damage claims against the company for damages to water, fish and wildlife resources.

- At 4 out of 14 mines (28%), partial tailings impoundment failures have occurred, and at 9 out of 14 mines (64%), tailings spills have occurred. These included a 1997 partial failure of the tailings impoundment at the Pinto Valley Mine, where 8.1 acres of creek bed and surrounding upland were buried under material as deep as 42 feet. In 1993, heavy precipitation caused the Gila River to flood and breach the tailings impoundment at the Ray Mine, carrying pollutants 11 miles downriver. And in 1980, 2.6 million cubic yards of tailings were released at the Tyrone mine, and flowed 8 kilometers downstream.

CONCLUSION:

Our research shows that water quality impacts to surface and/or groundwater are common at currently operating copper porphyry mines in U.S., resulting from three failure modes (pipeline spills or other accidental releases, failure to capture and treat mine seepage, and tailings spills or impoundment failures).

These failures resulted in a variety of environmental impacts, such as contamination of drinking water aquifers, contamination and loss of fish and wildlife and their habitat, and risks to public health. In some cases, water quality impacts are so severe that acid mine drainage will generate water pollution in perpetuity.

This research demonstrates that the three failure modes identified in the Bristol Bay watershed assessment with respect to risks to water quality are reasonable and well-supported by the track record of operating copper porphyry mines in the U.S.

Many of the currently operating copper porphyry mines are located in the arid southwest, where precipitation is limited, and communication between surface and groundwater resources is limited. While beyond the scope of the analysis in this report, more significant impacts could be expected at mines in wetter climates, with abundant surfacewater and shallow groundwater, such as is the case in the Bristol Bay region. Research shows that mines with high acid generating potential and in close proximity to surface and groundwater are at highest risk for water quality impacts. [2]

Table 1
2010 copper production amounts for mines reviewed in this report.

Mine	Location	Company	2010 Copper production (Metric Tons)
Bingham Canyon	UT	Kennecott/Rio Tinto	250,000[3]
Morenci	AZ	Freeport	233,146[4]
Ray	AZ	ASARCO	105,051[5]
Bagdad	AZ	Freeport	92,079[6]
Mission	AZ	ASARCO	83,415[7]
Sierrita	AZ	Freeport	66,678[8]
Robinson	NV	Quadra	49,400[9]
Tyrone	NM	Freeport	37,194[10]
Silver Bell	AZ	ASARCO	21,000[11]
Chino	NM	Freeport	15,400[12]
Mineral Park	AZ	Mercator	14,605[13]
Miami	AZ	Freeport	8,100[14]
Pinto Valley	AZ	BHP	6,000[15]
Continental Pit	MT	Montana Resources	Not available
Total production of 13 mines			982,068
Total U.S. production			1,100,000
Percent of total production			89%

Table 2

Synopsis of pipeline spills, tailings spills and impoundment failures, and water capture and treatment failures for 14 copper porphyry mines (1986-2012).

Mine	Number of reported pipeline spills and other accidental releases*	Water collection and treatment failures	Tailings dam failures	Affected surface and/or ground water
Morenci	21	Yes		San Francisco River, Gila River, Chase Creek, groundwater aquifer
Bingham Canyon	28	Yes		72 square mile plume of contaminated groundwater; fish and wildlife habitat in the Great Salt lake ecosystem
Ray	54	Yes	Partial	Mineral Creek, Gila River, groundwater aquifer
Chino	10	Yes		Hanover/Whitewater Creek, contaminated groundwater will require water treatment in perpetuity
Bagdad	7	Yes	Partial	Boulder Creek, Burro Creek, Butte Creek, Bridle Creek
Sierrita	18	Yes		Demetrie Wash and its tributaries; groundwater aquifer including drinking water wells in Green Valley
Pinto Valley	3	Yes	Partial	Pinto Creek
Mission	3	Yes	Partial	Tributaries of the Santa Cruz River, groundwater aquifer
Robinson	8	Unknown		2.3 miles of downstream drainage bed
Tyrone	7	Yes	Partial	Mangas Creek, groundwater contamination will require water treatment in perpetuity
Mineral Park	3	Yes		Groundwater aquifer and surface water
Miami	8	Yes		Pinal Creek alluvial aquifer
Silver Bell	3	Yes		Cocio Wash
Continental Pit	2	Yes		Groundwater aquifer

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

CASE STUDIES:

MORENCI MINE, AZ (Freeport McMoRan) The Morenci Mining District is located in southeastern Arizona, near the towns of Clifton and Morenci. It is located near the Gila River, the San Francisco River and Eagle Creek.	
Reports of pipeline failures and other accidental releases*	2008: Report of pipeline spill releasing 186,000 gallons of sulfuric acid and heavy metals into a tributary (Chase Creek) of t he San Francisco River, resulting in a $150,000 settlement with the State of Arizona.[16] The highly acidic material traveled downstream more than 2 miles. The pollutants in the discharge exceeded Arizona surface water quality standards for copper, zinc and pH in Lower Chase Creek. 2007: Report of release of 1,200,000 gallons of pregnant leach solution released due to power failure.[17] 2006: Report of release of 3,000 pounds of sulfuric acid from pipeline break.[18] 2006: Report of 1,127 pounds of material from PLS pipeline.[19] 2006: Report of release of rich electrolyte (acid content 1,057 pounds) from an underground process pipeline.[20] 2004: Report of release of 8,920 pounds of sulfuric acid and water from process pipeline due to failure of valve.[21] 2001: Report of release of 6,350 pounds of sulfuric acid released from pipeline.[22] 2000: Report of release of 72,000 gallons of sulfuric acid released from pipeline.[23] 1998: Report of release of 66,200 pounds of sulfuric acid released from pipeline.[24] 1996: Report of release of unknown amount of pregnant leach solution spilled from pipeline, affecting Chase Creek, leading to San Francisco River.[25] At the time of report, 20 gpm were being released. 1996: Report of release of 160,000 gallons of process solution spilled due to pipeline weld failure.[26] 1996: Report of release of 50,000 pounds of sulfuric acid spilled due to backhoe hitting pipeline.[27] 1996: Report of 12,435 pounds of sulfuric acid released from pipeline.[28] 1995: Report of 2,980 pounds of sulfuric acid released from pipeline.[29] 1994: Report of 203,400 gallons of raffinate released due to ruptured pipe.[30] 1994: Report of 5,400 pounds of sulfuric acid released due to fractured weld in pipeline.[31] 1993: Report of unknown amount of copper sulfate released into San Francisco River due to storm event.[32] 1993: Report of 180,000 gallons of pregnant leach solution spilled due to plugged drain line, affected 1 acre .[33] 1992: Report of 2,500 gallons of electrolyte released.[34] 1992: Report of 15,000 pounds of copper sulfate spilled due to valve failure.[35] 1992: Report of 7,500 gallons of electrolyte spilled due to failure of pipeline weld.[36]
Water collection and treatment failures	In 2012, the U.S. Dept of Justice and the State of Arizona released a consent decree which found that, "mine tailings exposed to air and precipitation released hazardous substances on the surface of the tailings or that can percolate through the tailings to groundwater." The consent decree found that, "releases of hazardous substances at or from the Morenci mine site have occurred and allege that such releases have caused injuries to natural

	resources at and in the vicinity of the site including surface water, sediments, soils, terrestrial habitats and terrestrial receptors."[37] A financial settlement followed an investigation of natural resource injuries related to the release of hazardous substances into the environment from acid mine drainage and process solution, among other sources. The investigation found that the main ore minerals are sulfide minerals, which have resulted in the development of acid mine drainage. According to the report, "Surface water has been, and most likely continues to be, exposed to hazardous substances released from the Morenci Mine through a variety of pathways."[38] Concentrations of hazardous substances measured in groundwater at the Morenci Mine and measured in the San Francisco and Gila Rivers downstream of the mine provide further indications that hazardous substances present in the source materials at the Morenci Mine have been released to the environment. The report found that "Concentrations of total and dissolved zinc have exceeded 1,000 ug/l in the Gila River and concentration of dissolved copper have exceeded 100 ug/l in the San Francisco River."[39] Contaminated groundwater is also released to surface water via seeps and springs.[40]
Tailings spills and impoundment failures	No impoundment failures.
Impacts to water, fish and wildlife	In 2012, the US Department of Justice and Department of Interior have jointly announced that Freeport McMoRan has agreed to pay $6.8 million to settle federal and state natural resource damages related to the Morenci Mine. According to the complaint, the hazardous substance release, which included sulfuric acid and metals, injured, destroyed or led to the loss of "surface waters, terrestrial habitat and wildlife, and migratory birds." [41] As described above, metals contamination occurred in the San Francisco and Gila Rivers downstream of the mine, and to groundwater supplies.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

BINGHAM CANYON MINE and SMELTER, UT (Kennecott) The Bingham Canyon Mine is the deepest open pit mine in the world, located southwest of Salt Lake City, Utah.	
Reports of pipeline failures and other accidental releases*	2011: Report of malfunction of equipment that allowed the release of approximately 145,424 gallons of copper tailings.[42] 2011: Report of pipeline overflow onto soil with estimated 100,000 – 290,000 gallons of copper tailings material released from pipeline.[43] 2011: Report of tailings slurry released from tailings slurry hot box. 160,000 gallons of tailings released.[44] 2010: Report of a release of process water due to broken pipeline. 2010: Report of a discharge of sulfuric acid from a pipeline in the precious metal plant released between 4,000-5,000 gallons.[45] 2007: Report of a release of 35,000 gallons of hydromet tail s containing arsenic due to pipeline break.[46] 2007: Report of 1,240,000 gallons of process water containing arsenic from pipeline break due to cold temperatures.[47] 2006: Report of 270,000 gallons of process water released because of pump failure, which resulted in overflow of containment area.[48] 2006: Report of 660,000 gallons of process water containing arsenic released due to cracked pipe.[49] 2006: Report of 1,000,000 gallons of process water released from the Magna Reservoir due to a failed level indicator.[50] 2004: Report of 4,000,000 gallons of process water with arsenic from pipeline.[51] 2004: Report of 2,000,000 gallons of process water with arsenic from broken process water line.[52] 2004: Report of 202,000 gallons of process water released due to pipeline failure.[53] 2003: Report of 70,000 gallons of process water with arsenic released due to pipeline failure.[54] 2003: Report of 70 tons of copper concentrate released from pipeline.[55] 2003: Release of copper concentrate, containing 340 pounds of arsenic, 20,000 pounds of copper, and 200 pounds of lead.[56] 2003: Copper concentrate pipeline ruptured, releasing 240,000 tons of copper, 428 tons of arsenic, 253 tons of lead.[57] 2002: Report of 5,800 gallons of process water from slag pot cooling area due to plugged drain line.[58] 2001: Report of tailings pipeline failure, releasing 4 pounds of arsenic, 14 pounds of chromium and 1 pound of lead.[59] 2000: Report of 110 tons of ore slurry released due to a leak in ore line.[60] 2000: Report of 18,000 tons of sulfuric acid released from pipe due to flange failure.[61] 1999: The process water pipeline sprung a series of leaks in 1989 and 1999. It has been estimated that 100 million gallons of process water with high arsenic levels spilled before the leak was discovered.[62] 1998: Report of copper sulfate released into a canal. 1998: Report of clogged piping system causing pipe to back up and overflow releasing acid

	rock drainage into water. 1997: Report of settling pond overflow due to clogged outlet valve. Release of copper sulfate into water. 1997: Report of pipeline rupture releasing process water (pH 2.5-4.0) into water. 1993: Report of 45,000 gallons of wastewater spilled due to a rupture of the transfer line.[63] 1991: Report of 30,000 gallons of industrial wastewater spilled at the wastewater treatment plant due to line break.[64]
Water collection & treatment failure	2011: Noncompliance in April-June 2011 for discharges of copper, zinc and t otal suspended solids at copper smelter.[65] Wastewater from the mine has escaped the site's collection system, contaminating groundwater with acid, metals and sulfates. The groundwater plume extends towards the nearby Jordan River and covers more than 72 square miles – rendering water for thousands of Salt Lake City residents undrinkable.[66] There have been multiple tailings spills.[67] Drainage from the waste rock piles will require water treatment in perpetuity to prevent additional groundwater pollution.[68] In February 2008, the United States Fish and Wildlife Service took legal action against Kennecott for the release of hazardous substances from the mine's facilities, including selenium, copper, arsenic, lead, zinc and cadmium.[69] Groundwater contaminated by mine operations has been released from the mine site through artesian springs into areas that serve as fish and wildlife habitats. According to the federal biologists, the release of these hazardous pollutants has harmed natural resources, including migratory birds and their support ecosystems, which includes wetlands, marshes, freshwater wildlife habitats, playas and riparian areas and freshwater ponds.[70]
Impacts to water, fish and wildlife.	In February 2008, the United States Fish and Wildlife Service took legal action against Kennecott for the release of hazardous substances from the mine's facilities, including selenium, copper, arsenic, lead, zinc and cadmium.[71] Groundwater contaminated by mine operations has been released from the mine site through artesian springs into areas that serve as fish and wildlife habitats. According to the federal biologists, the release of these hazardous pollutants has harmed natural resources, including migratory birds and their support ecosystems, which includes wetlands, marshes, freshwater wildlife habitats, playas and riparian areas and freshwater ponds.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

RAY MINE and HAYDEN SMELTER, AZ (ASARCO) The Ray Mine is a copper mining facility of approximately 6,100 acres near Kelvin, Arizona which discharges into Mineral Creek, a tributary of the Gila River, and the Hayden Facility is a smelting facility located in Hayden Arizona along the Gila River.	
Reports of pipeline failures and other accidental releases*	2012: Potable water line ruptured, which washed tailings into the Gila River. [72] 2007: A leak from a coupling in a tailings pipeline spilled tailings onto the banks and into the Gila River. A $20,000 civil penalty was paid.[73] According to the report, the pipeline had been in use since the construction of "d" tailings impoundment (about 1985), was in good condition, and was visually inspected on a frequent basis. A support structure failed on Feb. 4, 2007, resulting in an angular deflection at one of the couplings, resulting in the tailings leak.[74] 2007: Report of 1,000 pounds of sulfuric acid spilled from pipeline.[75] 2006: Report of 600 gallons of sulfuric acid spilled due to piping failure inside of mine.[76] 2000: Report of 80.95 pounds of copper sulfate released from basin/dam into Mineral Creek.[77] 2000: Report of 200 gallons of copper sulfate spilled from pipe.[78] 1999: Report of 33,000 gallons of tailings water released from pipeline.[79] Between August 1988 and November 1997, 47 separate releases of hazardous substances into Mineral Creek from the Ray Mine were reported. [80] According to a 2012 ecological risk assessment prepared by the State of Arizona, "A large portion of these releases were uncontained and eventually entered Mineral Creek and the Gila River. Hazardous chemicals released included copper sulfate, copper tailings and leachate."[81] In addition, the report found that multiple groundwater wells down gradient of the Ray Mine were found to be highly contaminated by a common leachate solution which was attributed to releases to shallow groundwater along Mineral Creek, and it concluded that "it is likely that the hazardous substances present in shallow groundwater will represent an ongoing source of chronic contamination to Mineral Creek (Lipton 2009)."[82] According to a report by the U.S. EPA, at least 19 spills of hazardous materials were reported at the Ray Mine from August 1990 through November 1993.[83] The majority of spills were from dams, pipelines, and ponds. The discharges typically resulted from either accidental discharges associated with heavy rain or from chronic seepage from leaching facilities into the ground water, which then entered the creek. The report found that, "surface water quality has been significantly affected." A total of 41 violations of total copper, dissolved copper, and beryllium numeric surface water quality standards were documented by the Arizona Department of Environmental Quality (ADEQ), EPA, and ASARCO in Mineral Creek below the Ray Mine.[84] According to the report, "Arizona's Department of Game and Fish believes that the discharges from the Ray Unit have negatively affected both the water quality and the aquatic life of Mineral Creek. The Department conducted a biosurvey of Mineral Creek in July 1993. In a report dated September 30, 1993, the Department found that although the numbers and diversity of aquatic insects and fish were high above the Ray Unit, an almost complete absence of aquatic life at sampling stations was observed directly downstream of the mine."[85]
Water collection and	According to an EPA report, "The mine's routine operations are chronically affecting the quality of both surface and ground waters in the mine's vicinity."[86] According to the report, the Arizona Dept. of Environmental Quality reported in 1996 that approximately

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treatment failures	one-half mile of the Mineral Creek streambed below the Ray Mine was visibly affected by mine activities. The streambed was coated with a blue-green layer of copper oxides.[87] In April 1995, EPA reported that six ground water wells situated downgradient of the electrowinning plant and the electrowinning dam were continuously pumping PLS.[88] Multiple groundwater wells were found to be highly contaminated by a common leachate solution which was attributed to releases by ASARCO into shallow groundwater along Mineral Creek. It concluded that it is likely that the hazardous substance present in shallow groundwater will represent an ongoing source of chronic contamination to Mineral Creek (Lipton 2009).[89]
Tailings spills and impoundment failures	2012: Seepage from the tailings impoundment was released into two catch basins and into a tributary of the Gila River. [90] At the time of the report, seepage into the tributary was estimated at 75 gpm. The incident occurred as a result of operator error during the initiation of a new upstream construction method at its Elder Gulch Tailings Impoundment in 2011. [91] A delay in the completion of the tailings distribution line resulted in the uneven distribution of the tailings, which in turn caused the ponded water to migrate, and eventually be released from the impoundment into drainages.The seep was discovered on January 30, 2012, and seep flow from the embankment was observed to have stopped on February 7, 2012. 2011: A report of 6,000-8,000 tons of copper ore tailings released from one of the tailings pond due to a breach in the dike.[92] The company failed to operate and maintain all listed permitted facilities in its Aquifer Protect Permit No. P-100507 to prevent the unauthorized discharge of copper ore tailings.[93] In 1993, heavy precipitation caused the Gila River to flood, and breach the AB -BC tailings impoundment containment dike. [94] According to a report by the U.S. EPA, "Continued flooding over the next several days resulted in a total of 13 separate breaches of the dike, three of which eroded through the dike and into the toe of the tailings pile. The total discharge was approximately 292,000 tons of tailings, which was about 216,000 cubic yards of material."[95] It also found that sampling of the river showed that elevated concentrations of pollutants occurred at least 11 miles downstream of the spill. The tailings formed bank and bottom deposits in the river, impairing both recreational uses and the quality of habitat for plants and animals.[96]
Impacts to water, fish and wildlife	In April 2009, the Department of the Interior and the State of Arizona, acting as natural resource trustees (Trustees) received a monetary settlement and three parcels of land from ASARCO, L.L.C. through the Natural Resource Damage Assessment and Restoration (NRDAR) program to account for injuries to trust resources incurred through multiple releases of hazardous substances by ASARCO L.L.C. into Mineral Creek and the Gila River in Pinal County, Arizona. [97] According to a 2012 ecological risk assessment by the State of Arizona, "The site of injury stretches from the Ray Mine and the Hayden Facility, to the Gila River from the Ashurst-Hayden Diversion Dam, upstream past the confluence of the San Pedro and Gila Rivers, and for a distance of 5 miles up each of those rivers beyond the confluence and to Mineral Creek from its confluence with the Gila River upstream to a point one mile above the Big Box Canyon Dam." The most substantial injuries occurred in the reach of Mineral Creek that extends from the tunnel outlet to the Gila River. The report finds that, "Dissolved copper concentrations in the surface water of this reach have been recorded up to 130 times surface water quality standards that will sustain aquatic life, and sediment copper concentrations have been recorded to exceed up to 22 times the level beyond which injury is inflicted on sediment-dwelling organisms (MacDonald et al. 2000)." These concentrations of copper caused a complete loss of aquatic life in this reach.[98] Overall, the report found that, "ecosystem services lost in the 117 acres that include Mineral Creek and its associated riparian habitat were estimated to be 100% from 1981-

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	2005, and up to 50% from 2005 to the present (Lipton 2009). Hazardous releases also affected the aquatic and riparian portions of the Gila River near the Ray Mine/Hayden Smelter Complex, including approximately 2,930 acres upstream of Mineral Creek to the confluence with the San Pedro River, and approximately 1,620 acres downstream of Mineral Creek to the Ashurst-Hayden Dam. The most substantial loss of ecosystem services in these areas occurred during the three years following the release of 300,000 tons of tailings in 1993, when ecosystem service losses were estimated at 10-25% (Lipton 2009)."[99]

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impactsresulted from the spill.

CHINO MINE, NM (Freeport McMoRan) The Chino Mine is located approximately 12 miles southeast of Silver City, New Mexico. The site is east of the Continental divide and drains into ephemeral drainages in the Mimbres watershed.	
Reports of pipeline failures and other accidental releases*	2007: A spill involving one million gallons of acidic mine waters overflowed a containment sump into a storm water diversion channel and traveled more than two and a half miles down a surface water tributary near the mine. The spill resulted in groundwater contamination and a settlement of $276,000 was reached with the State of New Mexico.[100] Multiple other tailings spills have occurred, which are listed below:[101] 2000: Report of 480,000 gallons of tailings slurry discharged, with 93,000 gallons entering Whitewater creek. 1999: Report of 3.25 million gallons of tailings spilled into Whitewater Creek. 1997: Report of 100,000 gallons of tailings spilled into Whitewater Creek. 1996: Report of 152,000 gallons of liquid tailings spilled into Whitewater Creek. 1993: Report of 208 tons and 91,500 gallons of tailings accidentally released to Whitewater Creek in six separate incidents resulting from the rupture of degraded pipes. 1992: Report of 120,000 gallons of tailings spilled into a basin. 1991: Report of 3,200 gallons of tailings released into Whitewater Creek when a tailings pipeline ruptured. 1988: Heavy rains led to the release of 180 million gallons of acidic wastewater into Whitewater Creek over a 35-day period. Analysis of the wastewater indicated that it had 30 times the allowed levels of the hazardous substance cadmium, as well as more than 30 times the allowed levels of sulfates.[102] Enlargement of the precipitation plant reservoir was completed in 1985 to prevent overflows of leachate solution into Whitewater Creek. Above average precipitation however caused the new reservoir to overflow and discharge waters to Whitewater Creek on October 9 and 10, 1985; May 6, 1986 and October 6, 1986.[103]
Water collection and treatment failures	In 2011, the U.S. Department of Justice and State of New Mexico issued a consent decree for damages to natural resources from hazardous substances from the Chino, Tyrone and Cobre mines.[104] The settlement followed an investigation of natural resource injuries related to the release of hazardous substances into the environment from acid mine drainage and process solution, among other sources. It found that, "surface water and associated sediments are exposed to hazardous substances released from the Chino Mine through a variety of pathways, including leaks and spills of process water, tailings spills; runoff, and infiltration or percolation from tailings and waste stockpiles."[105] Groundwater contamination from tailings pond #7, which became active in 1988, has occurred to the east, west and south of impoundment. It also found that hazardous substances have been released into groundwater at the Chino mine from multiple source areas.[106] Concentrations of hazardous substances in groundwater in exceedance of water quality standards confirm release to groundwater throughout the Chino Mine. Groundwater flow modeling for the North Mine area indicates that contaminated groundwater in four of these areas is n ot captured by dewatering in the main pit. In the South Mine area, groundwater has exceeded standards for manganese and cadmium at Middle Whitewater Creek, Hurley and Lake One, and has exceeded standards for copper at Lake One.[107]

	A 2012 assessment of groundwater impacts concluded that contaminated seepage from the mine will require water treatment in perpetuity.[108]
Tailings spills and impoundment failures	Tailings spills (see above).
Impacts to water, fish and wildlife	The 2003 ecological risk assessment reported elevated concentrations of the hazardous substances copper and zinc in surface water from five different drainages at the Chino Mine, including Hanover/Whitewater Creek, Bayard Canyon, Bolton Draw, the unnamed drainage between Bolton Draw and Lampbright Draw and Lambright Draw.[109] The areal extent of injured alluvial and regional groundwater at the Chino Mine is 13,935 acres.[110] According to the closure plan for the Chino Mine, contaminated groundwater will require water treatment in perpetuity.[111]

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

BAGDAD MINE, AZ (Freeport McMoRan) The Bagdad Mine is an open pit copper and molybdenum complex 100 miles northwest of Phoenix, Arizona.	
Reports of pipeline failures and other accidental releases*	2009: Report of a broken pipeline causing a release of 2,378,500 gallons of sulfuric acid.[112] 2007: Report of 22,500 gallons of raffinate solution containing sulfuric acid spilled from a pond.[113] 2004: Report of 7,484 pounds of sulfuric acid released due to malfunction of pipe.[114] 2004: Report of 354 pounds of sulfuric acid released due to crack in pipe.[115] 1999: Report of 12,000 gallons of process water with residual chlorine spilled into Bridle Creek.[116] 1997: Report of 1,500 pounds of sulfuric acid due to pipeline failure.[117] 1997: Report of 7,200 pounds of sulfuric acid overflowed from pond due to drain blockage.[118]
Water collection and treatment failures	In 1996, the EPA and the state of Arizona announced that Cyprus Bagdad Copper Corp., a subsidiary of Cyprus Mineral Corp., paid penalties totaling $760,000 for discharging contaminated water from the Bagdad Copper Mine.[119] The discharges involved various facilities including tailings ponds, leach dumps, and a sewage treatment plant, but by far the major discharges came from the Copper Creek Leaching Basin, in which acidic, copper-tainted underground seepage entered Boulder Creek.[120] According to an EPA report, seepage of pregnant leach solution from the Copper Creek Leaching System was discovered in a receiving pool in Boulder Creek in 1991.[121] Studies indicated that instead of being contained by the Copper Creek Flood Basin, t he heavily contaminated solution seeped under the dam. The concentration of total copper in samples collected in the pool in Boulder Creek were as high as 76.4 mg/l. On March 29, 1993, U.S. EPA issued a Finding of Violation and Order against Cyprus.[122] According to a 2006 study that compared the water quality predictions made during mine permitting with water quality impacts during operations, although no water quality impacts were predicted during the permitting process, the following water quality violations occurred: Water quality monitoring (1998-2002) in Boulder Creek, found water quality exceedances for arsenic, lead, mercury, and selenium. In Burro Creek, there were water quality exceedances for copper and mercury. In Butte Creek, there were water quality exceedances for mercury and selenium[123]
Tailings impoundment spills and/or failures	
Impacts to water, fish and wildlife	Copper and low pH releases to ground and surface waters, hazards to aquatic life from solution releases beneath and over containment system dam. Water quality impacts to Boulder Creek, Burro Creek and Butte Creek.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

SIERRITA MINE, AZ (Freeport McMoRan) The Sierrita Mine is an open pit copper and molybdenum mining complex 20 miles southwest of Tucson, Arizona.	
Reports of pipeline failures and other accidental releases*	2011: Report of 849 gallons of sulfuric acid spills from a pipeline leak.[124] 2008: Report of 1,100 gallons of sodium hypochlorite spilled due to loose pipe.[125] 2005: Report of 1,000 pounds of sulfuric acid from a broken pipeline.[126] 2005: Report of 8,058 pounds of sulfuric acid released from a broken pipeline.[127] 2002: Report of 39,375 pounds of sulfuric acid spilled from a pipeline due to a separated flange.[128] 2001: Report of 1,209 pounds of sulfuric acid spilled from pipeline.[129] 2000: Report of 5,350 gallons of leach solution spilled from pipe.[130] 1998: Report of 160,000 gallons of mill tailings spilled into water due to overflow resulting from power failure.[131] 1998: Report of 40,000 gallons leach solution spilled from pipeline.[132] 1998: Report of 120,000 gallons of leach solution spilled from pipeline.[133] 1997: Report of 2,798 pounds of sulfuric acid spilled due to pipeline rupture.[134] 1997: Report of release of 8,000 pounds of sulfuric acid due to pipe joint failure.[135] 1996: Report of release of 3,000 gallons of sulfuric acid due to pipeline failure.[136] 1994: Report of another pipeline break allowed a discharge into Demetrie Wash of approximately 120,000 gallons of reclaim water.[137] 1994: Report of approximately 5,000 gallons of reclaim water were released as a result of a pipeline break.[138] 1993: Report of a leak in a pipeline transporting process water discharged approximately 200,000 gallons of a mixture of process wastewater and storm water run-off to an unnamed tributary of Demetrie Wash.[139] 1993: Report of Cyprus Sierrita discharging approximately 2,700,000 gallons into the same wash as a result of another pipeline break.[140] 1993: Report of approximately 450,000 gallons released to the wash in October 1993 by a broken pipeline.[141]
Water collection and treatment failures	From the summer of 1992 until December 1994, Sierrita discharged contaminated process water and storm water run-off to Demetrie Wash and its tributaries from various overflows, seepages, and pipeline leaks and breaks.[142] In 1996, the U.S. Department of Justice issued a civil claim against Cyprus Sierrita on behalf of the State of Arizona and the U.S. pursuant to the Clean Water Act.[143] Cyprus Sierrita entered into a Consent Decree to pay a penalty of $88,000 for numerous violations. According to a 2011 report, seepage from an unlined tailings pond at the Sierrita mine has sent a plume of contaminated groundwater toward the city of Green Valley, causing drinking water wells to record high levels of sulfates.[144] In 2006, the company signed a mitigation order on consent with the State of Arizona to address sulfate in drinking water. It requires the company to develop a mitigation plan to be submitted in 2009.
Impacts to	Ground water and surface water contamination have occurred from pipeline leaks and breaks, overflows, and underground seepage from process wastewater, wastewater, and

water, fish and wildlife	storm water surface impoundments. Drinking water wells have been affected.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

PINTO VALLEY MINE, AZ (BHP Billiton) The Pinto Valley Mine is an open pit copper and gold mine located about 126 km east of Phoenix, AZ. Formerly owned by Magma Copper Company.	
Reports of pipeline failures and other accidental releases	2010: Report of a storm event, which caused 5,362 tons of tailings to spill onto soil and Pinto Creek, including 214 pounds of arsenic and 11 pounds of lead.[145] 500 cubic yards were released into water. Pinto Creek is a tributary to Roosevelt Lake. 2010: Report of an unknown amount of mine tailings released onto land, with a potential release to water, due to heavy rains.[146] 2007: A release of impounded storm and seepage water occurred due to a flange separation in a tailings line. The unexpected release washed out a section of the secondary containment, which allowed it to escape. An estimated 45,000 gallons of water (stormwater and tailings seepage) reported to an unnamed tributary to Pinto Creek.[147] 2001: Report of 1,725 pounds of sulfuric acid released due to pipeline break.[148]
Water collection and treatment failures	According to a 2001 EPA report, a portion of Pinto Creek from its headwaters to Spring Creek was first listed as water quality limited in 1992 based on elevated copper concentrations and pH values that were related to discharges from the Pinto Valley and another mine. The remaining portions of the stream were adde d to the 303(d) list in 1994.[149] The report further states that, "Since 1989, extreme storm events caused releases of copper bearing sediments and liquids to Pinto Creek from Pinto Valley operations. These releases resulted from partial tailings dam failures, pipeline breaks, seepage flows, conveyance blockages, and storm water overflows. Recent significant release events occurred in August 1989, July 1990, January 1991, August to September 1991, January to February 1993, and October 1997. In each of these events, materials were released in quantities sufficient to impact Pinto Creek or its tributaries."[150] Based on EPA's review of discharge monitoring reports between January 1990 and September 1991, Magma (now Pinto Valley) reportedly discharged effluent to Pinto Creek or its tributaries in excess of allowable effluent limitations on numerous occasions, and/or did not collect and analyze samples, in violation of permit conditions.[151] According to the report, during the first episode, approximately 3,000 gallons of effluent containing total suspended solids and copper of unknown concentrations was discharged from the ditch. A similar discharge of 24,000 gallons occurred on September 5, 1991. An estimated 39,000 gallons of effluent in exceedance of Arizona Surface Water Quality Standards and Aquifer Water Quality Standards for copper, zinc, and lead were discharged from the ditch on September 23, 1991.[152]
Tailings spills or failures	In 1997, a partial tailings failure deposited an estimated 276,000 cubic yards of tailings in Pinto Creek.[153] It buried 8.1 acres of creek bed and surrounding upland with material as deep as 42 feet.[154] Another incident occurred in 1993, when heavy rainfall overwhelmed the mine's water management capabilities. During the rainfall event, a reservoir overflowed the tailings pile, tore out a levee, and carried tailings to Pinto Creek.[155] In addition, a retention pond that held storm water and mineral wastes discharged material into the creek after its dam was breached. According to an EPA report of the incident, "Critical water containment structures in place at the mine in 1992 were reportedly designed to hold a 100-year, 24-hour storm event. Nonetheless, the mine discharged hundreds of tons of tailings and millions of gallons of contaminated water into Pinto Creek."[156] Water quality sampling during January and February 1993 indicated 286 exceedances of daily and monthly water quality parameters. Fish surveys collected before and after the discharges showed a

	marked decline in populations of the desert sucker (*Pantosteus clarki*) following the discharges. Although they were abundant in 1992, a summer survey in 1993 found only one adult in Pinto Creek.[157] In January 1991, the face of Tailings Dam No. 3 failed, releasing 150 - 250 tons of tailings into Pinto Creek, and two million gallons of water .[158] In March 1991, another large quantity of tailings was released from the same pile.[159] This release occurred from an over-saturation of the tailings face benches due to heavy precipitation, and an estimated 3.4 million gallons of water also were discharged.
Impacts to water, fish and wildlife	Extensive impacts to surface water quality and fish habitat in Pinto Creek resulting from tailings spills, and other mine related impacts.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

MISSION COMPLEX MINE, AZ (ASARCO) The Mission Mine complex is an open pit copper mine and underground copper mine located near Sahuarita, Arizona (18 miles south of Tucson). The Mine covers approximately 29.7 square miles, and a portion of the mine occupies tribal lands.	
Reports of pipeline failures and other accidental releases*	2011: Report of a backup of a tailing line resulting in release of tailings into a dry wash.[160] 2002: A violation involving the discharge of primarily copper laden stormwater runoff and process water discharge to ephemeral tributaries of the Santa Cruz river near Tucson in violation of the facilities Multi Sector General Permit Case # 09-2002-0064. 2001: Report of a 36-inch distribution tailings line releasing 200 tons of tailings into a dry stream channel.[161]
Water collection and treatment failures	According to EPA fact sheet released in 2008, discharges from mine (outfall 001A) contain significant levels of copper and lead, and TSS, which have been out of compliance since October, 2003.[162] Outfalls from the Mission complex discharge to ephemeral streams that are tributaries to the Santa Cruz River. Three large tailings ponds and several mine dumps are located on land leased from the Indian landowners approximately 1 mile south of the Arroyos project area. According to a report by the Bureau of Reclamation, leachate from these tailings has contributed to elevated levels of sulfate, TDS, and hardness in the aquifer below and adjacent to the ponds.[163]
Tailings spills or impoundment failures	The Bureau of Reclamation Report also states that, "Surface drainage from a break in a tailings pond dike in 1990 released large volumes of material into wash complexes that drain toward the SCR."[164]
Impacts to water, fish and wildlife	Ground and surface water pollution.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

ROBINSON MINE, NV (Robinson Nevada Mining Co.) Formerly owned by BHP Copper, Magma Nevada Mining Company The Robinson Mine is an open pit copper and gold mine located in eastern Nevada approximately 11 km west of Ely, Nevada.	
Reports of pipeline failures and other accidental releases*	1996: The mine experienced eight reported spills during 1996. Most of these spills involved tailings solution and reclaim wa ter releases due to equipment failures. The five spills resulting in releases of copper flotation tailings had spill volumes ranging from 1,500 gallons to 66,000 gallons. Four of these spills resulted in contamination of relatively small areas of soil. The largest spill resulted in contamination of a downstream drainage bed for 2.3 miles with an average flow path width of 3 ft. Two spills resulted in a combined release of 76,000 gallons of reclaim water.[165]
Water collection and treatment failure	In 2010, the State of Nevada issued a Finding of Alleged Violation and Order for the failure to comply with permit and regulatory requirements regarding stabilization of spent ore and associated acid rock drainage at the Intera and Green Springs area.[166] The Order requires the mine to "submit a plan by May 11, 2010 stating whether the Mill-Water Ponds, the overhead standpipe near the Mille-Water Ponds, and any other leaking pipes or tanks in the area, will remain on the Liberty Dump or be moved off the Liberty Dump (and any other potential sources). If the Mill-Water Ponds will remain on the Liberty Dump, specify whether they will be replaced, or tested and repaired to demonstrate integrity of primary and secondary liners. If the ponds will be tested and repaired to demonstrate integrity, include a complete description of the proposed methods to be used for NDEP review and approval."
Tailings spills and impoundment failures	Tailings spill (see above)
Impacts to water, fish and wildlife	Contamination of downstream drainage bed for 2.3 miles from mine tailings process water. (See above)

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

TYRONE MINE, NM (Freeport McMoRan) The Tyrone Mine is located approximately 10 miles southwest of Silver City, New Mexico. The mine straddles the Continental Divide.	
Reports of pipeline failures and other accidental releases*	2006: Report of a spill occurring when a CTI tanker truck loaded with about 3,000 gallons of acid collided with a pickup truck, spilling about 500 gallons of the acid on the highway and adjacent property.[167] (non pipeline) 2003: Report of approximately 2,600 gallons of 16% sulfuric acid solution spilled at the Tyrone mine during maintenance activity on a pipeline system.[168] 2001: Report of 500-1000 gallons of solution leaked from the pipeline.[169] 2001: Report of 300 gallon spill of raffinate and organic solution from pipeline. 2001: Report of 150 gallon spill from the Seep 5# pond, which overflowed with 75 gallons entering Deadman Canyon. Seepage had a pH of 4 and Deadman Canyon was flowing at approximately 50 gpm at the time.[170] 1997: Report of 65,000 gallons of raffinate leaked from a ruptured weld in a raffinate pipeline.[171] 1997: Report of a transfer line rupture due to cold weather. 1994: Report of No. 2 diesel fuel oil from two broken pipes detected in groundwater.[172] 2012 report identifies diesel fuel contaminant concentrations in groundwater from a leak in distribution pipeline at diesel tank farm, which migrated to re gional aquifer.[173]
Water collection and treatment failures	In 2011, the U.S. Department of Justice and State of New Mexico issued a consent decree for damages to natural resources from hazardous substances from the Tyrone, Chino, and Cobre mines.[174] The settlement followed an investigation of natural resource injuries related to the release of hazardous substances into the environment from acid mine drainage and process solution, among other sources.[175] According to the investigation, "groundwater in both the regional aquifer and the perched groundwater aquifers at the site have been exposed to hazardous substances through a variety of pathways."[176] The assessment at the Tyrone Mine identified 14 different mine area sources that have affected water quality, including seepage from tailings impoundments, leach stockpiles and waste rock stockpiles. A 2012 groundwater assessment concluded that contaminated seepage from the mine will require water treatment in perpetuity.[177]
Tailings spills and impoundment failures	There have been multiple spills of tailings, releasing hazardous substances. The largest event occurred at the No. 3 tailings dam in 1980, spilling 2.6 million cubic yards of tailings into the Mangas Valley.[178] Tailings flowed 8 kilometers downstream and inundated farmland.[179] The failure occurred due to a dam wall breach. 2001: 5 tons of tailings spilled into the Mangas Wash from the stormwater containment dike at the tailings dam.[180] 1990: Minor tailings spills from the No. 1 tailings pond in January 1990, and similar minor spills from the No. 2 tailings pond during 1990.[181]
Impacts to water, fish and wildlife	Streams and washes in the vicinity of the Tyrone Mine facility are ephemeral – they flow only after significant precipitation events. According to the 2003 preliminary assessment, "Surface water is exposed to hazardous substances released from the Tyrone Mine through a variety of pathways. Mangas Creek,

	an ephemeral stream adjacent to the Mine, which becomes perennial at Mangas Springs has been exposed to hazardous substances through spills and potentially through runoff and erosion."[182] The areal extent of the contaminated groundwater plume at the Tyrone Mine is 6,280 acres.[183] Groundwater seepage will require water treatment in perpetuity (see above).

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

MIAMI MINE, AZ (Freeport McMoRan; formerly owned by Phelps Dodge and Cyprus Amax Minerals) The Miami Mine is an open pit mine located 90 miles east of Phoenix, Arizona.	
Reports of pipeline failures and other accidental releases*	2011: Report of 1,600 pounds of sulfuric acid spilled from pipeline due to faulty weld.[184] 2009: Report of 1,000 pounds of sulfuric acid spilled due to pipeline break.[185] 2007: Report of a release of 9,450 pounds of sulfuric acid from pipeline.[186] 2001: Report of a release of 153 pounds and 6.4 pounds respectively of lead/arsenic from pipeline.[187] 2001: Report of a release of 2,070 pounds of acid plant blowdown from pipeline.[188] 1997: Report of 10,000 gallons of copper sulfate due to overflow of tank.[189] 1996: Report of 50,000 gallons of sulfuric acid due to tank failure.[190] 1996: Report of 8,995 pounds of sulfuric acid due to leaky pipe.[191]
Water collection and treatment failures	The Pinal Creek drainage was designated a Water Quality Assurance Revolving Fund (WQARF) site by the Arizona Department of Environmental Quality in 1989 due to acidity and metals contamination in the alluvial aquifer. The WQARF program is the state equivalent of the Federal "superfund" program. The Miami Mine, inherited from the Cyprus Miami Mine (formerly the Inspiration Mine) is a member of the Pinal Creek Water Quality Assurance Revolving Fund (WQARF) Site.[192] The Pinal Creek site was listed under the Arizona Water Quality Assurance Revolving Fund program in 1989 for contamination in the shallow alluvial aquifers within the Pinal Creek drainage near Miami, Arizona.[193]
Impacts to water, fish and wildlife	The Water Quality Assurance Revolving Fund (WQARF) program is the state equivalent of the Federal "superfund" program. The Miami Mine, inherited from the Cyprus Miami Mine (formerly the Inspiration Mine) is a member of the Pinal Creek Water Quality Assurance Revolving Fund (WQARF) Site.[194] The Pinal Creek drainage was designated a WQARF site by ADEQ in 1989 due to acidity and metals contamination in the alluvial aquifer.[195]

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

SILVER BELL MINE, AZ (ASARCO) The Silver Bell Mine is an open pit copper mine located on the southern edge of the Silver Bell Mountains.	
Reports of pipeline failures and other accidental releases*	2010: Report of 3,983 pounds of sulfuric acid released due to pipeline failure.[196] 2006: Report of 90,000 gallon release of raffinate; a mixture of 5.5 grams per liter of sulfuric acid and various metals. The release was due to equipment failure of a 24-inch mining pipeline.[197] 2002: Report of 242,000 pounds of process solution (with 1300 pounds of sulfuric acid) spilled due to power failure and overflow of solution pond.[198]
Water collection and treatment failures	In 2009, Silver Bell was fined $170,000 for three spills totaling 340,000 gallons of wastewater containing sulfuric acid and heavy metals into dry washes .[199] The pollutants seeped into soil, which endangered the groundwater in the aquifer below the mine and exceeded water quality standards. Two of the spills are described as such: Between Nov. 6 and Dec. 11, 2006, 150,000 gallons of leach solution containing sulfuric acid and metals escaped from a leaking impoundment. And between Nov. 11 and Dec. 13, 2006 another 100,000 gallons of stormwater containing sulfuric acid and heavy metals escaped from a storage pit. According to an EPA report, during site inspections of the mine in January and March 1993, the Arizona Department of Environmental Quality (ADEQ) observed water flowing in three unnamed washes below Silver Bell Mine.[200] Samples taken from the two streams flowing under the waste rock dump showed violations of standards for total selenium, with one stream also violating standards for dissolved copper. The third stream, which flows from the leach dump, showed a broader range of exceedances, and concentrations of copper in this stream were several orders of magnitude greater than the concentrations in the other streams. Analyses showed violations of standards for pH, total zinc, total cadmium, and dissolved copper.
Tailings spills and impoundment failures	Tailings spills (See below).
Impacts to water, fish and wildlife	According to a 2000 report on native fish populations by Pima County, "The loss of native fish along Cocio Wash is a good example of the potentially damaging effects that mining can have on aquatic ecosystems. Summer floods in July and August 1981 swept gray clay sediments from a Silverbell Mine tailings pond into the wash. BLM biologist Bill Kepner later reported, Our studies indicate that the Cocio Wash topminnow population is now extinct in that habitat due to recurrent mine spills and inundations by mine tailings... (Fonseca, 2000)."[201]

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

MINERAL PARK MINE, AZ(Mercator) Mineral Park is an open pit copper mine in the Cerbat Mountains near Kingman, AZ.	
Reports of pipeline spills and other accidental releases*	1996: Report of 150 - 200 gallons of sulfuric acid released from acid storage tank due to equipment failure.[202] 1996: Report of 200 gallons of sulfuric acid released.[203] 1996: Report of 1,100 gallons of sulfuric acid spilled. [204]
Water collection and treatment failures	According to a 1995 report by the Arizona Geological Survey, water quality samples were taken of streamflow just below the Mineral Park mine and of mine water seeping through a dam at the southwest end of the tailings.[205] Both samples showed extremely low pH values (3.2, 2.6), extremely high TDS values (5,549 and 6,625 mg/L) and extremely high sulfate contents (4,500 and 6,000 mg/L). According to the report, "the cadmium concentration of the stream flow just downstream of the Cyprus Mineral Park Mine place is 75.4 times higher than the standard, copper exceeds the standard 51 times and zinc 17.2 times." It further states that, "The discharge from the tailings ran down the washes until about two years ago, when the dam around the tailings was built. In years with very heavy rains the water could eventually reach the Sacramento Wash."[206] According to a 1999 EPA report, the Mineral Park Mine collected surface water samples from seven drainages and analyzed them for metals and radio-chemicals.[207] All of these drainages, except for Golden Eagle Spring, exceeded either the federal Maximum Contaminant Levels (MCLs) and or state guidelines for gross alpha or gross beta. According to the report, "ADEQ observed that surface water runoff emanating from the drainages in the mine area were affecting the water quality of the alluvial pediment." Data showed that the plume contained high levels of beryllium, cadmium, fluoride and nickel. The report further stated that, "the data show that TENORM is discharging from abandoned mine adits and is impacting surface water and that mining operations have impacted groundwater." [208] A 2006 technical feasibility report commissioned by the company also describes a plume of contaminated groundwater migrating down-gradient from the mine.[209]
Impacts to water, fish and wildlife	See above.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

CONTINENTAL PIT MINE, MT (Montana Resources) The Continental Pit is immediately adjacent to the Berkeley Pit in Butte Montana, and was initially known as the East Berkeley Pit. The Berkeley Pit and Continental Pit are included within the boundaries of the Silver Bow Creek/Butte Area Superfund site, which was established in 1983. Mining in the Berkeley Pit was discontinued in 1982, and in the East Berkeley Pit (now the Continental pit) in 1983. Mining was resumed in the Continental Pit by Montana Resources in 1986.[210] Because of their proximity, management of water and mine waste at the two mine sites are closely intertwined.	
Reports of pipeline spills and other accidental releases*	On January 28, 2009, an incident was reported to the Department involving a broken tailings line while crews were doing maintenance. The cause was attributed to a tailings line that was plugged with ice and a weld broke. The water was shut off within five minutes and no water left the site or reached state waters.[211] 1992: Department records show an accidental release of 0.34 million gallons in August of 1992.[212]
Water collection and treatment failures	According to a 1993 report, the sources of groundwater contamination in the Butte Mine Flooding Operable Unit of the Superfund Site were identified as: the underground workings; the walls of the Berkeley and Continental Pits; mine water in the underground workings; waste rock and tailings piles near the Berkeley Pit; leaking solutions from the leach pad and the Weed/MR Concentrator areas; leaking solutions from the Yankee Doodle Tailings Pond; contaminated soils and alluvium, and sulfuric acid added to the underground mines for copper leaching. Sources of water containing hazardous substances include: 1) process solutions from the historic Weed Concentrator and the current MR Concentrator.[213] Montana Resources suspended mining in the Continental Pit from 2000-2003 due to rising electricity costs.[214] During that time, about 7.5 billion gallons of water, or an average of 6 million gallons per day, went into the Berkeley Pit, to be combined with the highly acidic pit water already there. Montana Resources also diverted water from the Continental Pit into the Berkeley Pit for containment during their suspension. This contributed to increased water levels in the Berkeley Pit, and triggered the need to develop a water treatment plant to treat the contaminated water from the pit, which was rising to a critical level where contaminated pit water becomes an additional source of contamination to the surrounding aquifer and Silver Bow Creek. Under a consent decree with the State of Montana and US Department of Justice, a treatment plant was constructed and the mining companies are obligated to continue water treatment in perpetuity to prevent additional groundwater contamination.[215] Mine tailings from the Continental Pit mine are placed in the Yankee Doodle tailings impoundment, which also contains the mine waste from previous mining at the Berkeley Pit. The tailings impoundment is unlined, and seepage from the impoundment travels through faults and fractures into the Berkeley Pit. When mining ceases, seepage from the tailings impoundment will continue to contribute contaminated water to the Berkeley pit. As noted above, a consent decree requires contaminated water from the Berkeley Pit to be collected and treated in perpetuity.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

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